

Of four others :—

|                       | Transpiration time. | Boiling-point. |
|-----------------------|---------------------|----------------|
| Formic ether .....    | 0·511 .....         | 55·5           |
| Acetic ether .....    | 0·553 .....         | 74·0           |
| Butyric ether.....    | 0·750 .....         |                |
| Valerianic ether..... | 0·827 .....         | 133·5          |

Judging from these last observations, the order of succession of individual substances in any natural series will be indicated by the individual transpirability of these substances, as clearly as it is by their comparative volatility. Transpiration and boiling-point observations may come thus to claim an equal interest. In carrying out the inquiry, it will probably be found advantageous to transpire the liquids at a fixed temperature which is somewhat elevated. A large number of substances are liquid at 100° C., of which the transpiration times could easily be obtained. Slow transpiration and low volatility appear to go together, and both to be connected in a general way with a heavy molecule. So also the annexation of constitutional water to the hydrated acids and alcohols appears to impede the transpiration of these substances.

XX. “Electro-Physiological Researches.—Eleventh Series. On the Secondary Electromotor Power of Nerves, and its Application to the Explanation of certain Electro-Physiological Phenomena.” By Professor C. MATTEUCCI. Communicated by General SABINE, Treas. and V.P.R.S. Received June 2, 1861.

(Abstract.)

The object of this paper is to show by experiment that when a nerve is traversed by an electric current, it acquires in all its points a secondary electromotor power, and consequently becomes capable of producing in a conducting homogeneous circuit, whose extremities touch any two points of that nerve, an electric current in an opposite direction to that of the original current. This result is independent of the vital properties of the nerves, but is affected in greater or less degree by their physical condition. A similar effect indeed is produced by the passage of an electric current in all porous substances

imbibed with a conducting liquid, and the phenomenon has been studied in its generality by other physicists ; but the purpose of the present paper is to determine the conditions of the secondary electro-motor power of nerves, in order to make a due application of these conditions to the explanation of the phenomena exhibited by nerves on the opening of a voltaic circuit which has traversed them.

Having explained the object of his memoir, the author, before giving an account of his experiments, proceeds to describe certain improvements he has lately made in the instruments he employs for electrophysiological researches, whereby he is able more easily and effectually to avoid the risk of disturbing currents liable to be produced in the apparatus itself.

The fundamental experiment on which the main position of the memoir rests is performed as follows :—The sciatic nerve taken from a frog, a fowl, or some other recently killed animal, is used for the purpose. The operator first assures himself that no sign of current is manifested on simultaneously touching with the galvanometer two points of the nerve equidistant from its cut extremities. The disturbing effect of the electric current naturally generated in nerves may also be eliminated by placing two nerves, or two portions of nerve, in such relative position that their natural currents shall be opposed in direction and mutually neutralize their effects on the galvanometer. To the nerve or piece of nerve thus tested are applied, at some distance from its extremities, the electrodes of a pile of eight or ten elements, and the exciting or pile-current is allowed for a short time to pass along the included part of the nerve. When the nerve is now put in communication with the galvanometer, the needle deviates, and indicates that the nerve is traversed, in the portion which had been included between the electrodes of the pile, by a current the direction of which is opposite to that of the current of the pile, and which lasts for a certain time. Signs of secondary current are also obtained by applying the galvanometer to the parts of the nerve which have not been traversed by the pile-current, that is, the end-parts between the extremities of the nerve and the points touched by the electrodes of the pile ; but the secondary currents in these end-portions of the nerve are in the same direction as the pile-current, and therefore opposed to that of the secondary current developed in the part included between the electrodes and traversed

by the pile-current. It is further observed, that of the two end-currents the one adjacent to the point of application of the negative electrode is stronger than the other.

It is to be noted that the secondary current endures for some time after the cessation of the exciting current; hence it is evidently not caused by induction. The author thus explains its production:—At the points of a nerve which have been acted on by the electrodes of a pile the products of electrolysation are accumulated, and thence spread through the tissue more or less, according to differences of its structure and chemical disposition; conditions, persistent for a time, are thus established for generating a current when the circuit is completed between two different points of the nerve. The same thing happens when a strip of paper or flannel, moistened with a weak saline solution, is first subjected to the current of a pile and then tested with the galvanometer, or if such a strip is so tested after having been simply wetted at one part with acid and at another with alkaline solution, to represent the effect of electrolysation by an exciting current; and in either case the direction of the secondary current in the moistened strip, both in the part included between the points of application of the electrodes and in the excluded parts at the ends, corresponds with that in the nerve.

The experiment succeeds perfectly in the entire nerve of a living animal, such as the sciatic of a rabbit or a fowl. But the result is independent of the vital condition of the nerve, for the effect is found to be equally great four days after death as at the moment an animal is killed.

The author next gives the results of experiments made to determine the influence of various physical and chemical conditions on the secondary electromotor power of nerves. The method he generally followed was by comparing the secondary currents caused by the same pile-current in a natural and in an altered nerve. He had previously ascertained that when the same pile-current is passed through two nerves at once they are equally affected, and give when placed in opposition no differential deflection of the galvanometer, although singly each might give a secondary current of  $40^{\circ}$  or  $50^{\circ}$ . Now by sending the same pile-current simultaneously through two nerves or portions of nerve, either before or after the one of them has been subjected to the particular conditions to be tried, and finally placing the two in opposition in connexion with the galvanometer, the occurrence

or absence of differential deflection of the needle will show whether any or what degree of effect has been produced on the secondary electromotor power of the altered nerve. In this way the author found that both the cold of a refrigerating mixture and a heat of from  $50^{\circ}$  to  $60^{\circ}$  Cent. caused a great diminution of the secondary current in the nerves of a fowl. It is greatly weakened also by crushing the nerve, or by keeping the nerve long immersed in distilled water; immersion for a few seconds has no appreciable effect. Immersion for a few minutes in alcohol, or in a solution of potash of  $\frac{1}{2000}$  strength, entirely extinguishes the secondary current. Two nerves subjected to the same exciting current, the one fifteen or twenty minutes after the other, show no difference in their secondary currents. If an exciting current is passed through a nerve, first in one direction and then for an equal time in the opposite direction, the secondary current produced is weaker than if the pile-current had been in one direction only. The secondary current increases, within certain limits, with the duration, and also with the intensity of the pile-current. Neither the size nor the number of the nerves (if united by superposition) exercises any influence. Four similar nerves were subjected to the same pile-current; three of these nerves *superposed* were then placed in opposition to one as a differential pile, but no differential current was produced. Portions of nerve of equal length from a frog, a lamb, and a fowl, were subjected to the same pile-current, and when afterwards opposed successively, the one to the other, gave no differential current; yet singly each gave a secondary current of  $40^{\circ}$  or  $50^{\circ}$ . A decided effect, however, is produced by the length of the nerve; when pieces of different lengths were compared, a strong differential current was constantly found to correspond with the longest portion of nerve; the author remarks that this result cannot be understood, unless we admit that the secondary electromotor power, which is originally greatest in contact with the electrodes, extends successively to all the parts of a nerve traversed by the pile-current.

The author then comes to the fact which he conceives to be of greatest importance, in the application of the doctrine of the secondary electromotor power of nerves to the explanation of certain electrophysiological phenomena. It is expressed in the following proposition:—

*“The secondary electromotor power of a nerve is not equal in all parts of the nerve, being much stronger in the portion of the nerve near the positive electrode, than in that near the negative electrode ; and this difference is greater in a nerve which has been traversed by the current in the direction contrary to that of its ramification, than in a nerve traversed by a current in the same direction as its ramification.”*

The unequal intensity of the secondary current and its maximum near the position of the positive electrode, is shown by cutting an electrolysed nerve into two or more equal lengths, which are then severally opposed to each other in connexion with the galvanometer, and the greatest differential current is found to be produced by the part near the situation of the positive electrode. Again, the greater effect of a pile-current passed inversely to the direction of the ramification of the nerve, is shown by opposing two nerves which have been traversed in different directions by the same current ; or by dividing a nerve and opposing its two equal halves after they have been traversed in opposite directions by the same current.

The application of these facts respecting the secondary current in nerves to the explanation of the phenomena which take place in nerves on the opening of a circuit, is treated of in the concluding part of the paper, which we give with slight abridgement in the author's own words:—

“The object of these researches,” he observes, “was not to study the production of secondary electromotor power in nerves rather than in other porous and humid bodies of various structure and chemical composition. Under this point of view it is evident that the phenomenon is complex and its analysis difficult. In the present state of science, therefore, we are unable to account for the differences presented by a nerve in its different points, according to their proximity to one pole or the other, and the direction in which the nerve is traversed by the current. It is possible that similar differences will present themselves in other bodies not organized nor taken from living animals. It is sufficient for my present object to have proved that the secondary electromotor power of a nerve requires for its development the integrity of structure of the nerve itself, not, however, the excitability of the living animal ; and to have determined rigorously the differences of this power which have led me to ground

the explanation of the electro-physiological phenomena which take place on the opening of the circuit, on a fundamental physical fact.

“If in a frog prepared in the usual way for electrical experiments a continuous current is passed up one hind limb and down the other, for 15, 20, or 30 seconds, according to the force of the current, it is known that the opening of the circuit is accompanied by violent contractions of the limb traversed by the inverse current. These contractions depend, as I showed many years ago\*, on a particular state of the nerve; and in fact the contractions are obtained and continue when the circuit is interrupted by cutting the nerve near the spine, but they are no longer produced if the nerve is cut near its insertion in the muscles of the leg.

“My object in this memoir has been to prove that the particular state of the nerve above described consists in secondary electromotor power, that is, in a well-known physical phenomenon. The course of the secondary current, which is downward or direct in the nerve that has been traversed by the upward or inverse pile-current, explains, according to the well-known laws of electro-physiology, the effects produced by it on that nerve on the opening of the circuit.

“The differences of electromotor power found in various points of the electrolysed nerve, the prevalence of this power in the part of the nerve near the positive electrode, very probably also the different degree of this secondary electromotor power in the various strata which compose the interior and the envelope of the nerve, are circumstances which seem to explain the secondary current which takes place in the nerve at the opening of the circuit, and which is direct and most intense in the nerve which has already been traversed by the inverse current, most intense also in the vicinity of the positive electrode.

“In order, therefore, to explain the phenomena which accompany the opening of a circuit, we must henceforth have recourse to the fact of the development of secondary electromotor power in nerves and the laws according to which it manifests itself.”

\* Phil. Trans. 1847, pp. 235, 236.